CMHC
Canada Mortgage and Housing Corporation

SCHL
Société canadienne d'hypothèques et de logement

A Cogeneration Station for a Public Housing Development

Research Report

August 1983

Canada

Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

A COGENERATION STATION

FOR A

PUBLIC HOUSING DEVELOPMENT

PREPARED FOR

THE RESEARCH DIVISION

POLICY DEVELOPMENT AND RESEARCH SECTOR

CANADA MORTGAGE AND HOUSING CORPORATION

BY

COGENERATION ASSOCIATES LIMITED

TORONTO, ONTARIO

Principal Consultant, A. Juchymenko, P. Eng.

CMHC Project Manager, Philip Deacon

ABSTRACT

Cogeneration (the simultaneous provision of heat and electricity from the same fuel source) was examined for its potential application to residential developments. A case study approach was used where a moderately large public housing development of 327 suites in Toronto was analyzed for its energy use profiles. The seasonal and diurnal characteristics of space heating, domestic hot water, and electric power were compared to the mix of heat and electricity available from a cogeneration plant of the required overall size. For cost-effective cogeneration, the load factor (i.e. the percentage of capacity actually used over a year) must be high.

Overall, cogeneration was only suited to supplying base demand for domestic hot water and electric power, approximately one third of total energy demand. Generator requirements were modest; the optimum size was a 100KW engine which also gave out 186KW of heat. A spark-ignition reciprocating engine, fuelled with natural gas, was chosen as being the most economic.

Costs of retrofitting the building for this use were estimated at $105,000 and, at current prices, annual overall savings at $16,500 would be achieved. These savings are extremely sensitive to fluctuations in gas and electricity prices.

In general cogeneration was found to have limited application to the retrofit residential sector owing to:

- residential energy patterns having small base demands
- small size of required capacity, which implies high installation costs, but only modest savings
- sensitivity to utility rates, which implies that a narrowing of the gap between the costs of electricity and fuel, can quickly change savings into losses.

This study was conducted by Cogeneration Associates Limited for Canada Mortgage and Housing Corporation under Part V of the National Housing Act. The analysis, interpretations, and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation or those divisions of the Corporation that assisted in the study and its publication.

CONTENTS

	List of Illustrations	vii
	List of Tables	ix
	Preface	xi
	EXECUTIVE SUMMARY	xiii
1.0	INTRODUCTION	1
2.0	TECHNOLOGY INVOLVED IN COGENERATION	2
	2.1 Energy Balance	3
	2.1.1 Electricity Production	3
	2.1.2 Heat Balance	4
	2.2 Heat Recovery System	6
3.0	LOAD ANALYSIS	8
	3.1 Site Selection	8
4.0	ENERGY USE	10
	4.1 Space Heating	10
	4.2 Domestic Hot Water	11
	4.3 Electric Power Requirement	11
5.0	CONCEPTUAL SYSTEM DESIGN	18
6.0	ECONOMIC ANALYSIS	23
7.0	CONCLUSIONS	26
8.0	RECOMMENDATIONS	27
	APPENDIX A	28
	APPENDIX B	31
	APPENDIX C	34
	APPENDIX D	36
	APPENDIX E	39
	APPENDIX F	41

LIST OF ILLUSTRATIONS

		PAGE
FIG. 1	GAS ENGINE PERFORMANCE CURVES	5
FIG. 2	HEAT RECOVERY FROM RECIPROCATING ENGINE	7
FIG. 3	AVERAGE MONTHLY ELECTRICAL DEMAND	12
FIG. 4	LOAD DURATION CURVE	13
FIG. 5	ELECTRICITY POWER USE PROFILE	14
FIG. 6	ENERGY PRODUCTION FROM COGENERATION COMPARED TO DEMAND	22

LIST OF TABLES

		PAGE
Table 1	Energy use for space heating	15
Table 2	Energy use for domestic hot water	16
Table 3	Energy use for electric power	17
Table A-1	Energy produced + cost data (100KW)	29
Table A-2	Energy produced + cost data (150KW)	30
Table F-1	Monthly commercial electricity costs	42
Table F-2	Provisional rates of purchase by Ontario Hydro	43
Table F-3	Calculation of monthly electricity costs for Toronto	44

PREFACE

This study arose from a number of events that occurred quite close to each other. One was the appearance on the market of small and relatively cheap cogenerating equipment. The second was the emphasis that the National Energy Plan placed on conversion to natural gas and its "pegging" at approximately two thirds of the cost of oil. The third was the accelerating interest of commercial and industrial institution (such as hospitals and factories) in cogenerated energy. These led to speculation that cogeneration could be used to provide residential energy needs for a suitably sized development.

To compete with large scale generation of electricity, cogeneration has to achieve very high utilization factors, at (relatively) low demands. This study was to take an existing residential development and illustrate the general principles involved in specifying a suitable cogeneration plant, and to estimate the performance and costs of installation and operation. Finally it was to comment on the overall applicability of cogeneration for residential uses.

EXECUTIVE SUMMARY

Cogeneration is the term used to describe the provision of both heat and electricity from the same fuel source. Under the correct conditions the overall efficiency of such a system can be very high, and can result in substantial dollar savings, compared to the purchase of utility-generated electricity. This study looks at the possibility of using a cogeneration plant for an existing 327 suite apartment building in Toronto, owned by the Ontario Housing Corporation.

Each particular type of cogeneration plant puts out electricity and heat in a more or less fixed ratio, so the overall capacity of the plant has to be carefully chosen to fit in with the pattern of demand that is characteristic of the building. For residential buildings, there are three contributory demands:

- space heating
- domestic hot water
- electric power.

For cogeneration to work efficiently, the load factor (i.e. the percentage of capacity actually used over a year) must be high.

- Space heating is entirely seasonally dependent and it was found to be uneconomical to provide cogeneration capacity for this purpose.

- Domestic hot water is less seasonally dependent, and has a substantial base demand, coupled with large storage. This is highly suitable for cogeneration.

- Electric power is only slightly seasonally dependent but shows large hourly variations. Storage of electricity is not viable, but the utility companies will buy back cogenerated electricity. The rates, however, are barely economic.

Cogeneration is only suited to provision of electric power and heat for domestic hot water. Together, these account for approximately only one third of total energy demand, and this is the effective limit of cogeneration contribution. Thus, even for this quite large building, the size of the cogeneration plant is small. The recommended size is a 100 kW generator, which also supplies 186 kW of heat.

The economics of the plant are governed by the price ratio of electricity and natural gas, and the installation costs. The price ratio is largely under political influence via regulation, and future changes are difficult to predict. The ratio in Toronto is quite low compared to many other cities. Installation factors favour larger units because the cost, as a proportion of operating savings, is lower. Unfortunately, most apartment buildings are smaller than the one involved with this study.

In summary, the cogeneration plant chosen for this study would supply approximately one third of annual energy demand via power and domestic hot water. At current prices, the overall dollar saving would be about $16,500 per year. This is approximately 8% of gross energy costs. Installation costs would be approximately $105,000, giving a simple payback of 6.3 years.

Generally, cogeneration appears to have quite limited application in the retrofit residential sector. Local utility rates and size of building are the limiting factors. Installations in new buildings could be expected to be more attractive.

1.0 INTRODUCTION

In the long term, prices for heating fuels are likely to continue to rise faster than inflation. As home heating fuel prices increase in real terms, so must the amounts of money from the federal government allocated in the form of subsidies to cover energy costs for public housing.

Because the energy situation in Canada and the rest of the world can change so rapidly, governments became aware of the need for greater energy management, not only from the aspect of national security, but from a basic economic viewpoint. One area of concern has been that of the residential market, with a major emphasis being placed on single family dwellings. However, a major part of the residential market has yet remained relatively untouched by advocates of energy conservation through retrofit. This area covers multi-residential dwellings, such as medium and high rise apartment buildings.

The Canada Mortgage and Housing Corporation (CMHC) and the Treasury Board have ongoing commitments for subsidizing the operating costs of public housing, and a considerable portion of these costs are allocated for energy. Thus, as the cost of energy continues to escalate, so do the subsidies paid by CMHC. Given these circumstances, it is in the interest of CMHC to investigate equipment and systems which would use cheaper energy to reduce such subsidies.

One such system is cogeneration. Cogeneration can be defined as the simultaneous production of electricity and heat from the same fuel source. For the relatively small-scale generation required for a multi-residential building, a natural gas fired engine, with heat recovery equipment, is the most applicable technology. Natural gas is used to fuel the engine which turns the generator to produce electricity. The heat from the engine exhaust, as well as from the jacket (block) cooling water, is recovered and used to supply space heating and/or domestic hot water requirements. The overall cycle efficiency of such a system can be as high as 80%.

In order to determine the effectiveness of this system in reducing the cost of energy for an apartment building, one building of 327 units was selected for this purpose. It is owned and operated by the Ontario Housing Corporation and is located at 325 Bleecker Street in Toronto, Ontario.

2.0 TECHNOLOGY INVOLVED IN COGENERATION

There are several cycles which produce both electricity and heat in the cogeneration mode. The best known and widely used is the Rankine Cycle, using a steam turbine to turn a generator. The steam exhausted from the turbine is used to supply heat to processes in industry, or to provide hot water for district heating systems. In Canada, more than 1,000 MW of power is produced in this manner, mostly in the Pulp and Paper industry and the Chemical Products industry.

The next most important cogeneration technology is in the use of gas turbines to supply mechanical power. The high temperature exhaust of 450°C - 500°C is passed through a waste heat boiler where the energy in the exhaust is recovered. Several large installations exist in Canada. Of the best known, one is located at the Dow Chemical plant in Sarnia, one is at the electrical utility in Medicine Hat, and several are installed by Trans Canada Pipeline as heat recovery projects in their gas pumping stations.

Another important cycle that can be used for cogeneration, although it is not widely practiced, is an internal combustion engine to supply both heat and power. This was widely promoted by the natural gas companies in Canada and the U.S. in the sixties as a 'total energy system'. It consists of an internal combustion engine and heat recovery boilers which generate electricity and supply hot water for commercial applications, primarily buildings. Several large building complexes were designed and built utilizing this technology. In 1978 a large apartment/office complex in New York City was built where compression ignition (C.I.) engines were installed to supply all the required energy. In Canada, several such systems were installed in the Yukon and the Northwest Territories.

Both the steam turbine and gas turbine systems become more economic with larger installations and high capacity utilization factors. For small installations, an internal combustion engine is more appropriate. Therefore, for this particular installation, only internal combustion engines are considered.

There are two commonly used internal combustion engines; compression ignition (C.I.) and spark ignition (S.I.). The selection of the appropriate engine lies in the availability and price of fuels and the technical requirements of the installation. Although the performance of these engines is similar, they do differ somewhat in their cycle efficiency and quality and quantity of recoverable heat. The S.I. natural gas engine is selected for this application because of its lower price, lesser weight, and lower maintenance costs.

2.1 Energy Balance

Generally speaking, cogeneration supplies electricity and heat in a fixed ratio. This ratio can be changed to a small extent by the operating conditions. By and large, this balance governs the choice of equipment, because it has to match the application.

2.1.1 Electricity Production

Designers of cogeneration systems strive to obtain the highest possible yield of electricity from a given quality of fuel. Electricity, being a high grade energy, can readily be used at the site or sold to the electric utility. Most of the provincial electric utilities in Canada are willing to purchase a cogenerator's surplus power at an established rate. This ability to sell surplus power to a utility may permit the designer to opt for a larger generating unit,which can produce electricity at a lower unit cost than would be the case with smaller generating units. The degree of utilization of the system's output (heat and electricity) dictates the equivalent value of co-generated energy. If utilization is low, electricity may be sold to the utility at a loss. In Ontario, where there is a two-tier electricity delivery system, (municipal and Ontario Hydro), the purchaser of a cogenerator's surplus power would always be Ontario Hydro, even when the cogenerator is connected to a municipal utility, for the municipal utility acts as a 'wheeler' of power only. Therefore, the buy-back rates published by Ontario Hydro for purchasing cogeneration power apply to all cogenerators regardless of their location in Ontario. These rates include both a capacity rate and an energy rate. There

are no stand-by charges. (See Appendix F)

In other provinces, the utility which generates power is also the distributor of the electricity. A one-tier system such as this permits direct negotiations between a cogenerator and the generating utility.

Officials of electric utilities in Canada do not look unfavourably upon cogeneration, whereas in the U.S. the opposite is true. A majority of the U.S. utility policy makers are hostile to cogenerators, and this is reflected in much of the published data which is read by Canadian designers, who assume that the situation in Canada is the same. This confusion hinders the rational development of cogeneration in Canada.

2.1.2 Heat Balance

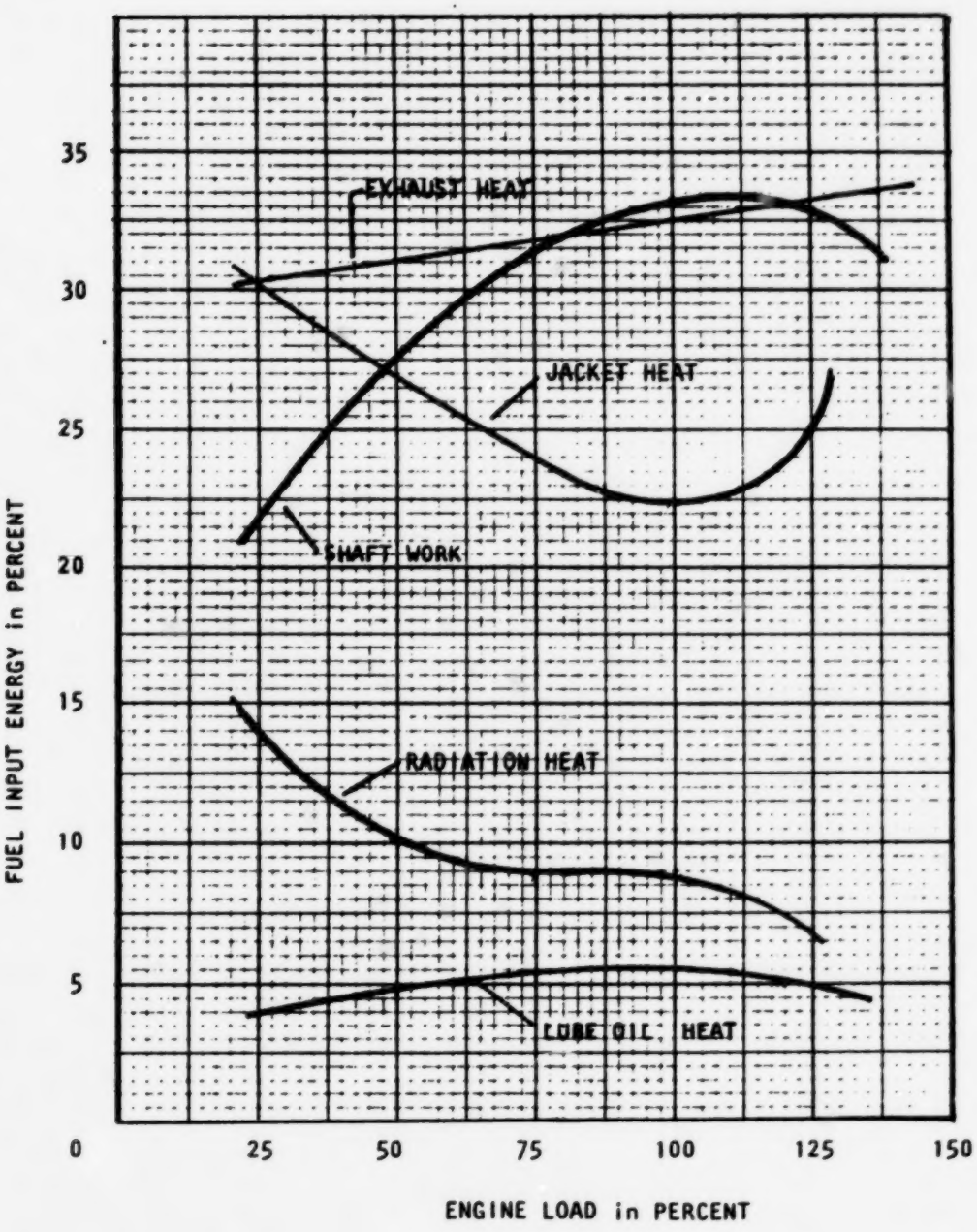
In the spark ignition engine there are three main sources of waste heat which can be recovered. They are as follows:

- .1 Heat rejected to exhaust
- .2 Heat rejected to coolant-jacket
- .3 Heat rejected to lubricating oil coolant

Figure 1 shows the percentage distribution of fuel input to each heat source. Exhaust heat is the largest source, but only 60% of it can be recovered in practice. This rejected heat is available at about 640°C from the S.I. engine at full load. Approximately 96% of heat from the engine block cooling jacket and lubricating oil cooling can be recovered as hot water at temperatures of up to 120°C. The temperature of the jacket cooling water affects the performance of the engine. By lowering the jacket cooling temperature from 120°C to 75°C, less heat is lost to the exhaust and to the lubricating oil cooling system, while more heat is lost to the jacket. Therefore, the designer of a cogeneration system has several options to consider when designing a heat recovery system.

FIGURE 1

GAS ENGINE PERFORMANCE CURVES



2.2 Heat Recovery System

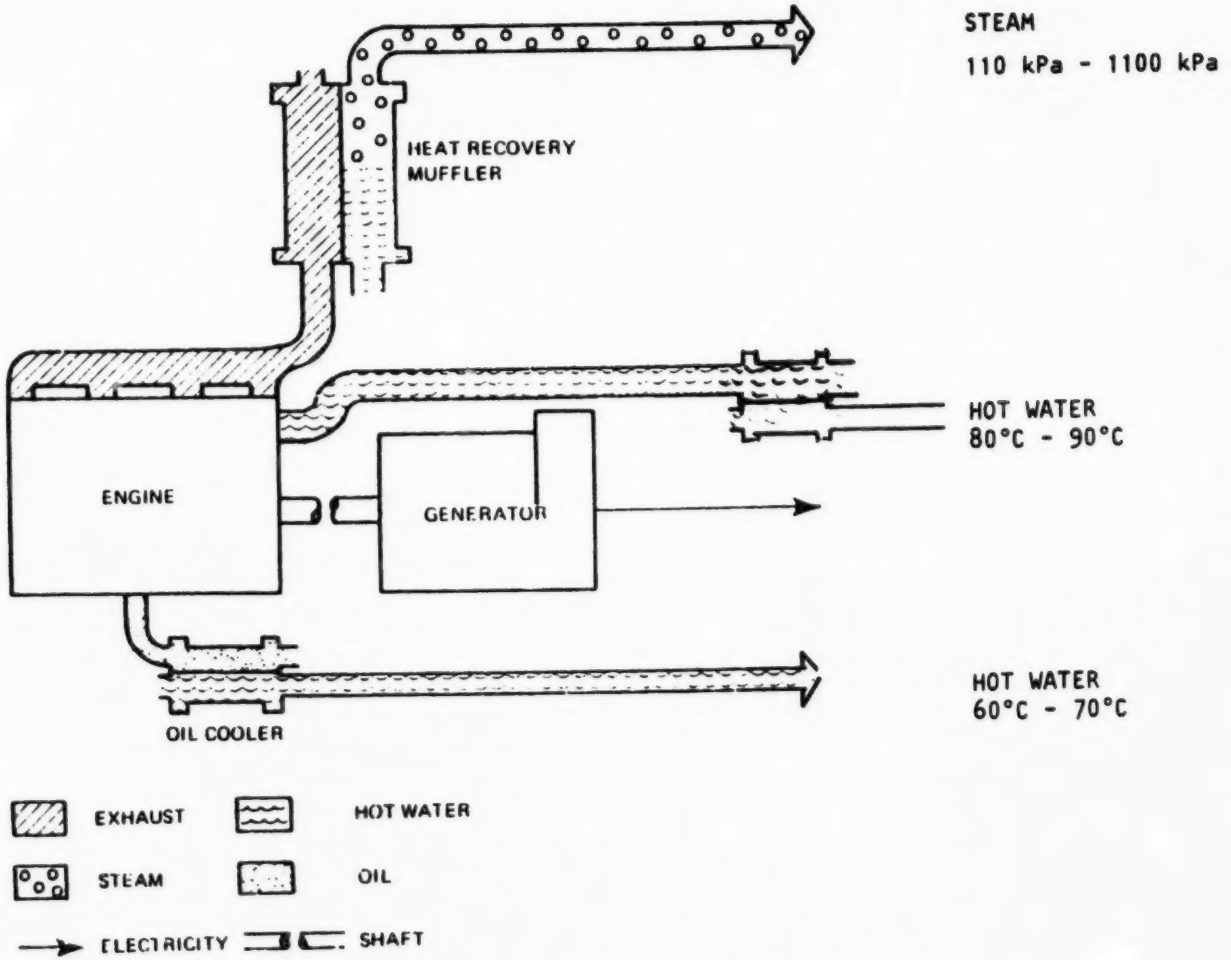
In order to optimize the cycle efficiency, all sources of waste heat should be considered for recovery. There are two heat recovery systems which are being used for commercial buildings. Their use is determined by the heat requirements of the building and by economics.

The simplest system recovers heat from exhaust gases, jacket cooling and oil cooling circuits, by means of heat exchangers. (Figure 2)
Low pressure steam or hot water can be obtained from the heat recovery muffler (exhaust gas). Hot water can be obtained from the jacket and the oil cooler heat exchangers. For heating domestic hot water, this system is both practical and economic.

A more sophisticated heat recovery system combines exhaust gas and an ebullient (boiling) jacket water boiler. This system produces low pressure steam (100 kPa) which is suitable as process heat.

FIGURE 2

HEAT RECOVERY FROM RECIPROCATING ENGINE EXHAUST GAS, JACKET COOLANT, AND LUBE OIL



3.0 LOAD ANALYSIS

3.1 Site Selection

Several apartment buildings were considered during the preliminary analysis. The criteria used in the selection of the study site for assessment of cogeneration is based on the technical and economic parameters, as outlined in a report prepared for the Ontario Ministry of Energy.*

In summary, the main parameters are as follows:

1. Size - Economies of scale play an important role in the production of electricity. Larger generating stations produce electricity at lower unit costs than do smaller stations. Therefore, the buildings considered for the study were to have as large a heating load as possible. It was assumed that the surplus electricity would be sold to Ontario Hydro.

2. Loads - Steady and continuous loads are the most suitable for cogeneration. The two loads considered for the heating energy from the S.I. engine are domestic hot water and space heating.

3. Heat balance - For an economic operation it is necessary to have the use of heat and electricity in a given ratio.

4. Fuel - The ratio of cost of fuel to the cost of electricity should be as low as possible. For this study it is assumed that the fuel used would be natural gas.

5. Operation - The cogeneration unit should operate automatically without an operator. Maintenance should be provided by an experienced firm and a maintenance schedule should be set under an annual contract.

* "Industrial Cogeneration in Ontario", Ontario Ministry of Energy, 1980, Cogeneration Associates Limited.

6. Data - The availability of energy use data was another important factor which was considered when selecting the site.

When all the factors were reviewed, the apartment building at 325 Bleecker Street in Ontario was selected. This building has 327 apartment units occupied mostly by families, and is operated by the Ontario Housing Corporation. It is part of a complex of 5,000 apartments in the St. James Town area of Toronto and was constructed in the early 1970's. It has an electric ceiling cable for space heating which is individually controlled in each apartment. Domestic hot water is heated in electric bulk boilers which are rated at 204 kW each (408 kW total). There are four large storage tanks with a total capacity of 65.3 m^3. This system is located in the basement. This building also has a swimming pool and a heated sports centre.

4.0 ENERGY USE

There are three major uses of energy in the selected building: domestic hot water (DHW), space heating (SH), and electric power. All the energy is supplied by the electric utility. In 1980,Ontario Hydro initiated a thorough energy use analysis for this building and some of the metered data has been published in a report.* All energy use data in this study comes from the report. The monitored energy use data for the 1980-81 period is used as a design parameter in this study. The total energy used in the building during this period was 6,045,600 kWh, which is within 1% of the 8 year average of 6,163,700 kWh for the period 1972-1979. The 1980-81 metered data was used for the sizing of the engine-generator set and the economic analysis. (Figure 3)

4.1 Space Heating

The 1980-81 energy consumption for space heating was 2,472,400 kWh distributed by month, as shown in Table 1. This table summarizes data which was collected at 15 minute intervals by a digital recorder. The actual monitored data was used to draw a load duration curve as shown in Figure 4.

Since all space heating energy is supplied by electricity, it would be difficult to retrofit this building to utilize hot water from cogeneration for space heating in individual apartments. However, energy can be added to the building by heating ventilation air. The present preheating system for ventilation air is only partially effective. When there is not enough warm exhaust air to preheat the required amount of ventilation air to a given tempeature, the ventilation air is reduced or even turned off. This procedure may save energy, but it does not improve the quality of air for the occupants. If hot water coils could be inserted into the ventilation (shaft) ducts, then both air quality and energy conservation would be accomplished at the same time.

*"Energy Management Control System in an All Electric Apartment Building", Ontario Hydro, Conservation and Utilization Division, Report #81-3, December 1981.

Apartment buildings heated with hydronic systems can easily be retrofitted to utilize hot water from the cogeneration unit. The energy from the cogeneration unit can supplement the existing fuel fired boilers. This would result in a highly efficient operation of the S.I. engine. Such high efficiency would occur only during the heating season when the heat from the engine can be utilized. In the summer, the only thermal energy required in apartment buildings is for heating hot water, which is a fraction of the space heating load in winter. Hence, in summer, the engine would be operating on part load, with a resultant loss of efficiency and higher cost per unit of generated energy.

4.2 Domestic Hot Water

Table 2 shows the 1980-81 total amount of energy use for domestic hot water (DHW) for the apartment building. The average electricity demand for DHW varies between 132 kW in summer and 190 kW in winter. Although the actual household demand for hot water varies significantly during the day, the water storage capacity allows energy input to the DHW system to remain at a constant rate. The storage capacity is 65.4 m^3, or 0.2 m^3 (44 gallons) per suite, which is large enough to satisfy the average consumption of 29.2 gal/suite as recommeded by Ontario Hydro.* In 1980-81, about 1,428,600 kWh of energy was used for DHW.

4.3 Electric Power Requirement

The total amount of power used by occupants of the building in the 1980-81 period was 1,517,600 kWh as shown in Table 3 . This power supplied mostly refrigerators, stoves, lights, television sets, etc. A small portion of this energy was used to operate elevators, fans, pumps, the laundry room, the sauna, etc. The highest average usage was accrued in March at 192 kW, and the lowest in July at 154 kW. The daily power profile for July is shown in Figure 5. The lowest hourly demand was recorded at 5:00 a.m. on week days. If cogeneration is used to supply power to a building, the power output would match the requirement of the building, and surplus power could be sold to the utility.

* 'Electric Heat Manual' Rev. May 1973, Ontario Hydro, Chapter 2, Table 1.

Figure 3

AVERAGE MONTHLY ELECTRICAL DEMAND

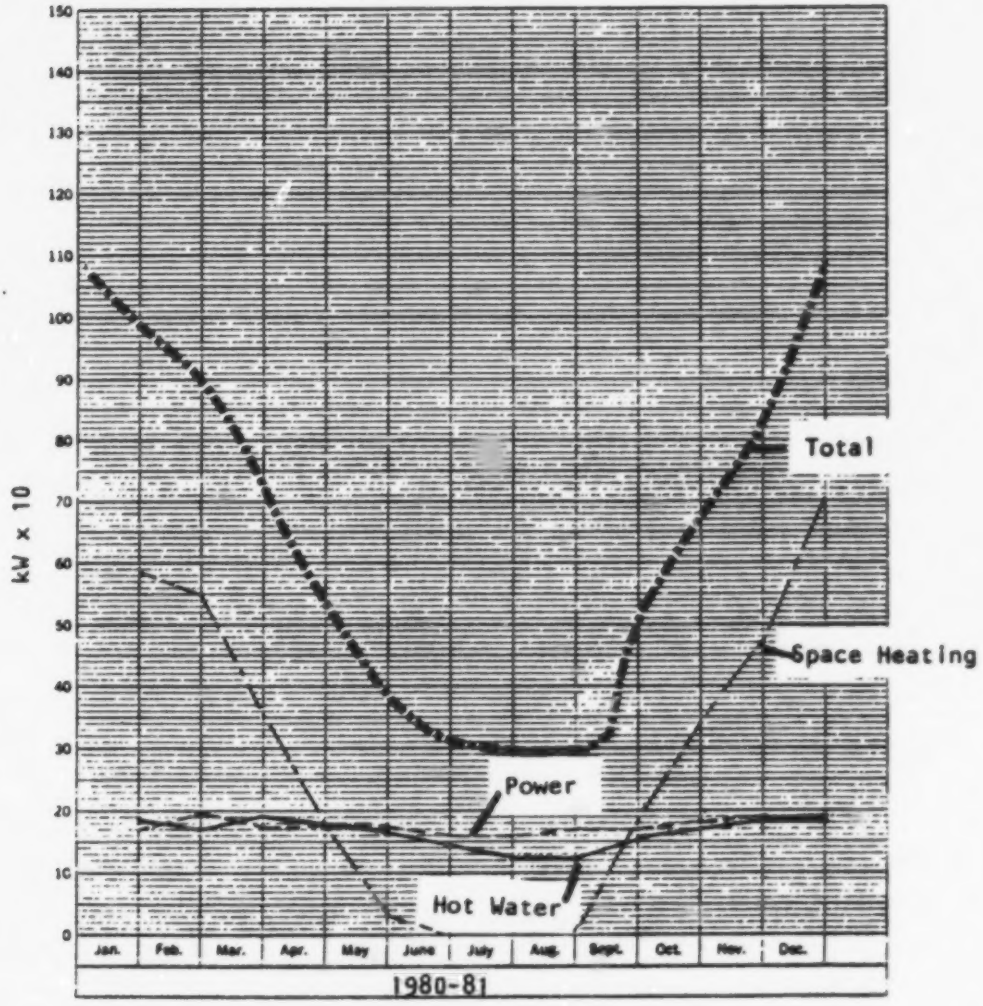


Figure 4

LOAD DURATION CURVE

SPACE HEATING

325 Bleecker St.

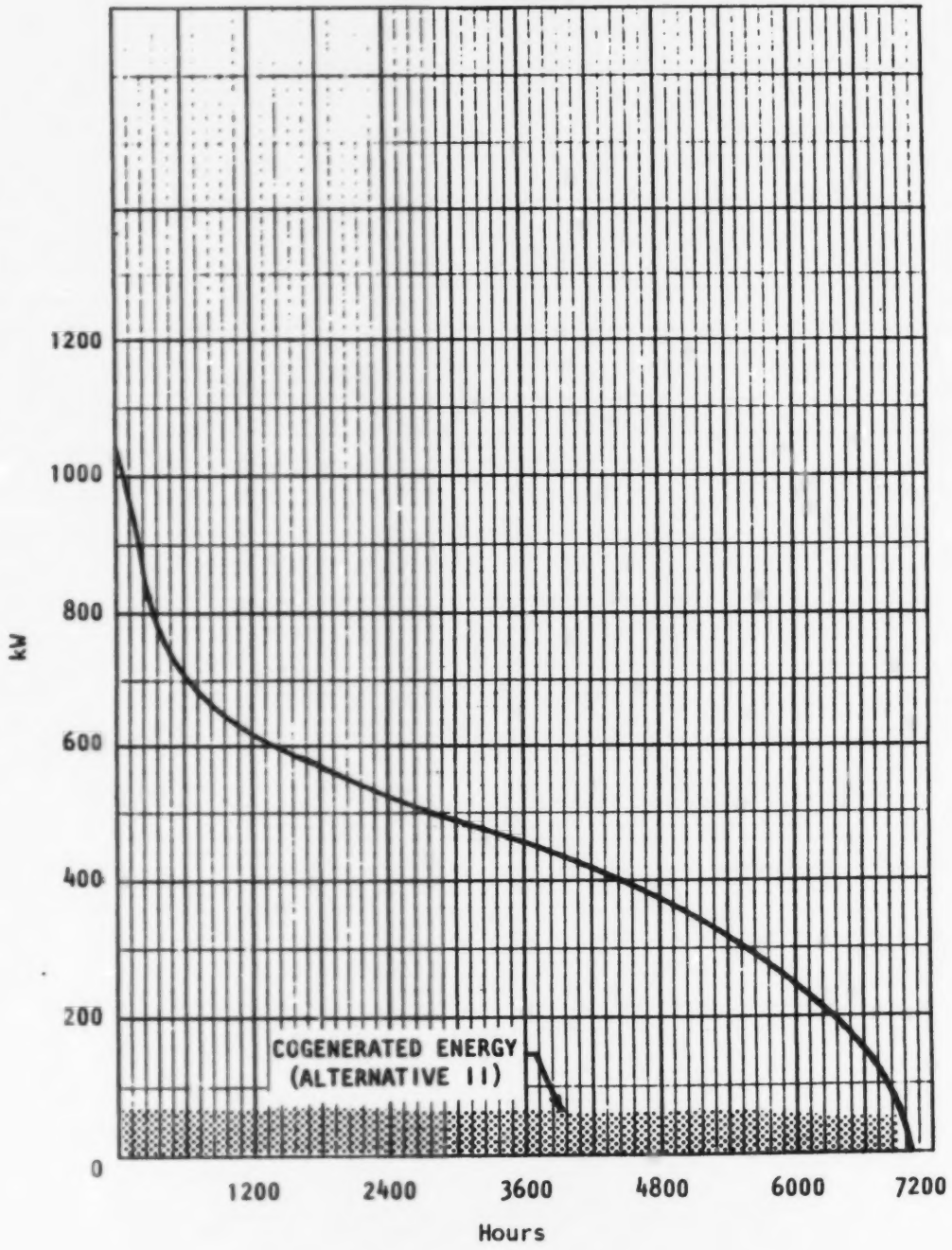


Figure 5

ELECTRICITY POWER USE PROFILE

325 Bleecker St.

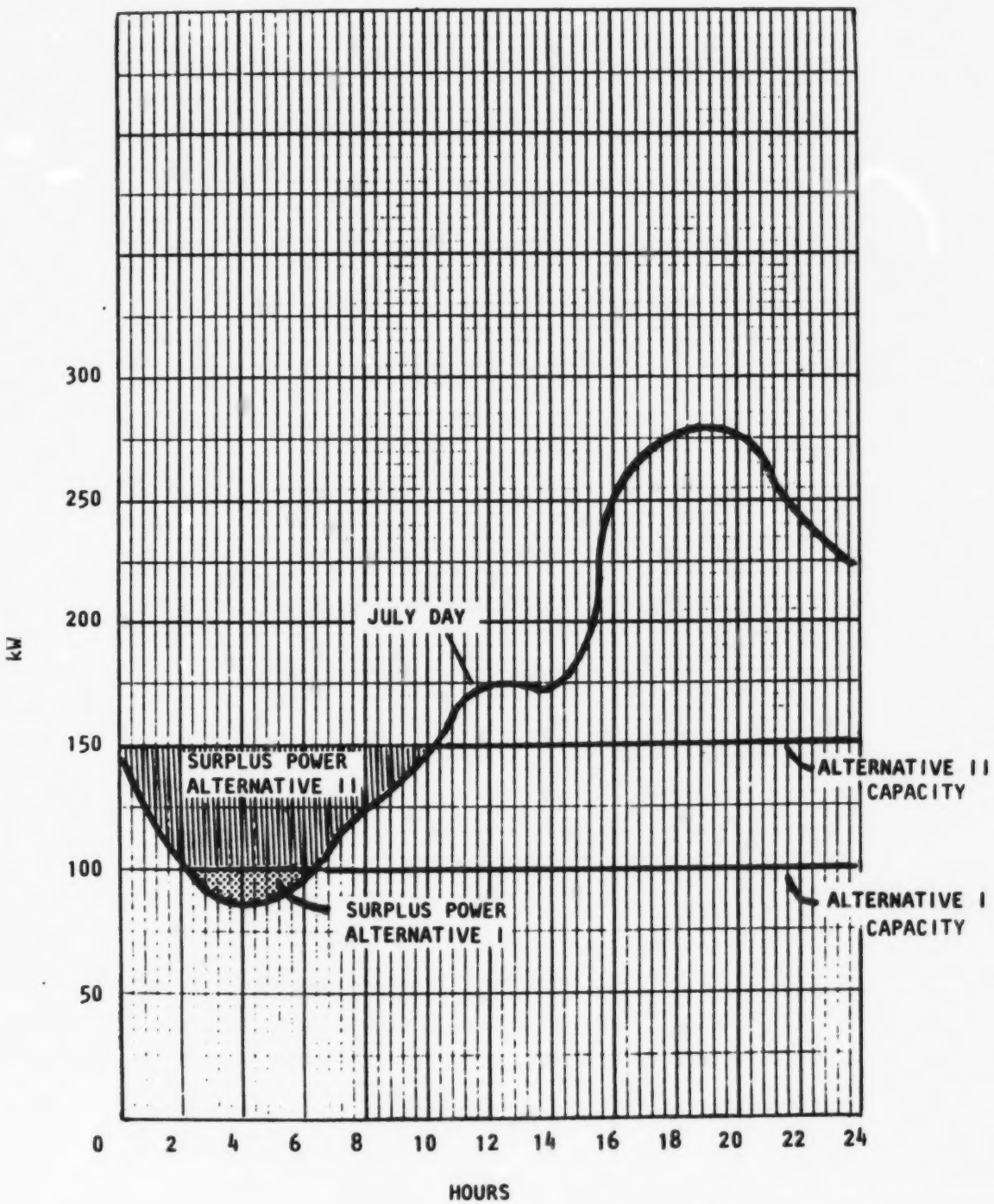


TABLE 1

ENERGY USE FOR SPACE HEATING (1980-81)

325 BLEECKER ST., TORONTO

Month	No. of Days Metered	Use '000 kWh	Average Demand kW
February (1980)	26	369.2	592
March "	32	424.0	552
April "	33	278.4	351
May "	31	137.0	184
June "	32	32.1	42
July "	29	-	-
August "	33	-	-
September "	29	-	-
October "	29	131.3	189
November "	30	238.2	331
December "	32	357.3	465
January (1981)	29	504.9	725
	365	2,472.4	

TABLE 2

ENERGY USE FOR DOMESTIC HOT WATER (1980-1981)

325 BLEECKER ST., TORONTO

Month	No. of Days Metered	Use '000 kWh	Average Demand kW
February (1980)	26	118.6	190
March "	32	141.1	184
April "	33	151.2	190
May "	31	132.5	178
June "	32	129.1	168
July "	29	101.8	146
August "	33	104.2	132
September "	29	92.2	132
October "	29	104.2	150
November "	30	118.1	164
December "	32	131.0	171
January (1981)	29	104.6	180
TOTAL	365	1,428.6	

Average hourly energy requirement for DHW is: $\frac{1,428,600}{8760} = 163$ kW

TABLE 3

ENERGY USE FOR ELECTRIC POWER

(1980-1981)

Month	No. of Days Metered	Energy Use '000 kWh	Average Demand kW
February (1980)	26	116.2	186
March "	32	147.8	192
April "	33	144.1	182
May "	31	121.2	167
June "	32	124.3	162
July "	29	107.5	154
August "	33	125.9	159
September "	29	116.8	168
October "	29	118.4	170
November "	30	129.5	180
December "	32	136.3	177
January (1981)	29	129.6	186
TOTAL	365	1,517.6	

Average hourly energy requirement for power is: $\frac{1,517,600}{8,760} = 173$ kW

5.0 CONCEPTUAL SYSTEM DESIGN

The S.I. engine cogeneration unit is designed to operate at a minimum efficiency of 76% at full load. In order to reach this efficiency, the engine must operate at a constant power output for most the the year. Two engines of different output ratings are considered for this site: Alternative I is a 100 kW engine and Alternative II is a 150 kW engine. (Figure 6)

Alternative I - A 100 kW engine producing 186 kW of heating energy for DHW only. Almost all the energy for this purpose could be supplied. It is estimated that the engine would be operated for 8074 hours per year. This operating schedule would allow about 300 hours for a weekly inspection of the engine, and two weeks for a major overhaul during the low energy requirement period in July. The balance of 360 hours is allocated to downtime and part-load operations. The total annual cogeneration heat production would be 2,118,614 kWh. The balance of the energy needed for DHW would be supplied by the utility.

Alternative II - A 150 kW engine producing 246 kW of heating energy. It would provide all the energy needed for DHW, and in winter it would contribute some energy for space heating. In the summertime, when the cogeneration unit supplies only the DHW requirement, the engine would be running at part-load.

The selected cogeneration units are physically small and easy to install in an apartment basement. With heat recovery equipment, the required mounting space is only about 5,000 mm by 2,000 mm, or roughly the size of one parking space. The exhaust would be carried to the outside with an appropriate muffler pipe arrangement. The air intake system would be ducted from the outside, with provisions for dampers which allow air intake from the garage during the summer, acting as a ventilation system. By installing the engine in the garage, the water connections and electric cable would be all inside the building, resulting in lower installation costs.

Furthermore, the radiation energy from the engine would partially heat the garage in winter.

The cogeneration unit would be operated in parallel with Toronto Hydro. In case of an engine failure, the circuits supplied with cogeneration power would be automatically switched to the Hydro system and a signal would be given to the supervisor of the building that the fault has occurred. A crew, under contract for maintenance and emergency repairs, would be called in to rectify the fault.

In the sizing of the engine generator set for the apartment building, there are four design limitations which have to be considered. They are:

1. Minimum daily heat requirement,
2. Minimum instantaneous power demand,
3. Toronto Hydro electricity rate,
4. Ontario cogeneration rate.

As is shown in Figure 3, the minimum daily heat requirement occurs in summer when there is no space heat needed and the DHW requirements are low. With the large storage tanks for DHW the rate at which energy is added can be varied from hour to hour during the day. This ability to store energy is very beneficial to cogeneration. In winter, the demand for DHW is much higher than in summer, and there is always the possibility of using cogenerated heat for space heating when there is surplus heat. For 325 Bleeker Street the minimum summer heat load is 132 kW.

The power demand is lowest during the night hours (1:00 a.m. to 6:00 a.m.). In Winter, when space heating is supplied by electricity, the total electric demand, as indicated in Figure 6, is much higher than the cogeneration capability. Between October and May, there are no constraints on power production and the operation of cogeneration. In the summer months, the night demand must be considered. The July night demand can be as low as 80 kW and, therefore, the engine will be operating at part-load during that time.

This partial load operation is reflected in the number of operating hours as indicated in Tables A-1 and A-2 in Appendix A.

If there is a demand for both heat and electricity, the cost of cogenerated energy, at 2.2¢/kWh, is lower than purchased energy, at 3.3¢/kWh. During the time when heat is not required, the cost of electricity production at full load is 5.85¢/kWh. (This would happen in Alternative II, when the engine would have more heating capacity in summer than the heating needs of the building). The reason is that if the heat is discarded, no equivalent value can be assigned to it, and all operating costs are assigned to electricity.

Selling power to Ontario Hydro from this cogeneration unit (150 kW) would not be profitable, since the maximum price that Ontario Hydro would pay is:

1.8¢/kWh and $4.28/kW/month in Winter, or
1.27¢/kWh and $2.35/kW/month in Summer

This means that at 80% (150 kW unit) load factor, the average price to Ontario Hydro would be 2.5¢ in winter and 1.7¢ in summer. With a fuel rate of 2.2¢/kWh, it is uneconomic to sell power to Hydro in summer, and only marginally economic in winter.

Toronto Hydro's rate is one of the lower rates when compared to other cities in Canada, as indicated in Table F-1 in Appendix F. If the electricity rates were higher, the economics of cogeneration would improve.

TABLE 4

FUEL RATE FOR G 342 (150 kW ENGINE)

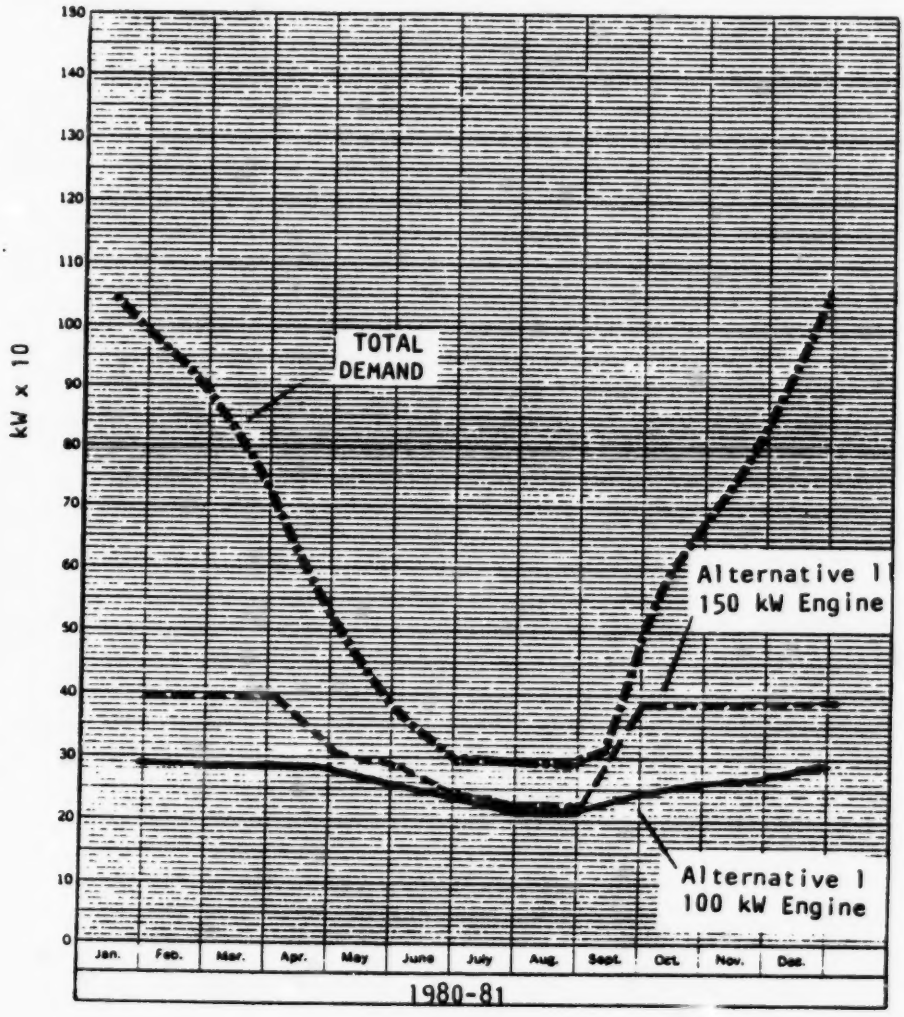
% of Load	Fuel Rate		Cost of Fuel (electricity)
	m^3/hr	m^3/kWh	¢/kWh
100	50.98	0.3399	5.85
75	39.92	0.3548	6.10
50	28.54	0.3805	6.54
25	16.24	0.4331	7.45

Based on natural gas at 17.2 ¢/m^3.

Figure 6

ENERGY PRODUCTION FROM COGENERATION

COMPARED TO DEMAND



6.0 ECONOMIC ANALYSIS

The pay-back periods for the two alternatives, as calculated in Appendix B, are as follows:

Alternative I - 100 kW Unit = 6.3 years
Alternative II - 150 kW Unit = 7.5 years

The smaller unit of Alternative I is a better investment because it would be running at a higher annual load factor of 89.2%,producing both 100 kW of electricity, and heat for most of the DHW energy requirement. The larger unit of Alternative II would have a load factor of only 80.7%. Furthermore, the capital cost per kW of installed capacity is higher for the larger unit because of the necessity to distribute a portion of the recovered energy for space heating. Although the space heating contribution from the cogeneration set is small at 56 kW, it requires a separate heat exchanger at the engine,and a distribution network in the building. The capital cost of the smaller unit is lower than for the 150 kW unit, because only one heat exchanger is used.

If an acceptable pay-back period for a cogeneration system is taken to be 5 years, then neither of the two alternatives meets this criteria at this site. However, the 100 kW unit comes very close to this pay-back at 6.3 years. If this was a new development where the DHW system cost would be credited to the cogeneration system, then the pay-back period would be substantially reduced. The present DHW boiler system in the building is rated at 408 kW, costing an estimated $22,000.

Furthermore, the installation costs for cogeneration in a new project would be lower,since the unit would be designed as part of the DHW system. Allowing for the DHW system credit and lower installation costs, the cogeneration unit would cost only about $53,000. When engineering costs and a contingency allowance of 25% is added, then the capital cost would be still only $66,250., giving a pay-back period of 4.0 years, which is well below the 5 year criteria.

Applying cogeneration to smaller and larger buildings than the one studied is practical. The limiting factor in all of these applications is the required balance between electricity and heat production. Also the demand must have a high load factor. When cogeneration supplies the DHW heating requirement, the system can be designed to operate at high efficiency and a high load factor. When cogeneration also supplies the space heating energy, then it runs at a lower load factor and lower efficiency, resulting in higher costs and higher pay-back periods. Installation costs,however, would favour larger buildings as the cost per kW of capacity decreases with size.

For electrically heated buildings (baseboard or ceiling cable),retrofitting the existing heating system is costly and uneconomic, as shown in Alternative II. However, for hydronic systems,the heat from the engine can be easily introduced into the hydronic system to supplement the existing heating system. Only additional piping and some pumping facilities would be needed to retrofit hydronic systems for a cogeneration operation.

The electrical rate structure plays an important role in determining the viability of a cogeneration system. The best sites are those where electricity costs are high and natural gas costs are low. The feasibility of cogeneration depends mainly on the ratio between the price of natural gas and the price of electricity, and to a smaller extent,on the price structure for electricity. An assessment of the role played by the rates for energy is beyond the scope of this study.

The life expectancy of the engine-generator set is estimated by the manufacturers to be 20 years, provided that the maintenance schedule is adhered to as specified. The average running time between major overhaul for natural gas engines is 14,000 - 25,000 hrs.,depending on the fuel and operating conditions. In cogeneration applications, for engines burning natural gas, the period between overhauls is estimated to be 25,000 hours. There are many reciprocating engines in remote northern communities which have provided a dependable service for more than twenty years.

The maintenance costs associated with cogeneration would be higher than those of the existing electrically heated, DHW or space heating systems, which are practically nil. The engine would require weekly inspections and monthly minor tune-ups. Oil changes, filters, and ignition adjustments would be required on a regular basis. Once a year, preferably in July when the load is lowest, the engine would undergo a major inspection and the required tune-up,which would include replacing worn parts. Every 3-4 years, a major overhaul would be required. The cost of this overhaul is included in the annual budget figure for operation and maintenance of $5,400 per year.

7.0 CONCLUSIONS

1. Technically, a spark ignition engine-generator set can supply both electricity and heat to an apartment building. Retrofitting presents no major problems.

2. An Engine-generator set, sized to supply energy only for a domestic hot water system, is more economic than a larger set which could also contribute energy for space heating purposes.

3. The energy requirement at 327 Bleeker Street Apartment building is as follows:

Electric Power	1,517,600 kWh
Space Heating	2,472,400 kWh
Domestic Hot Water	1,428,600 kWh
TOTAL	5,418,600 kWh

4. A 100 kW Cogeneration unit can supply 2,118,600 kWh/year or 39% of the total energy requirement of the building.

5. At the current energy prices, the saving in energy cost is about $16,500. a year. The installation of a 100 kW cogeneration system is estimated at $105,000., giving a simple pay back period of 6.3 years.

6. The utility rate structure plays an important part in determining the economics of cogeneration, as does the balance between electricity and heat production. Communities with high electrical rates and low natural gas prices are good candidates for cogeneration.

7. Although this technology can bring about savings, and its application from a technical point of view is viable, there are too many constraints to be overcome in order to make it very favourable for this application.

8.0 RECOMMENDATIONS

1. Although there are hundreds of engine-generating sets successfully operating in remote communities, mines and industrial establishments, there are no engine-generating units in Canada supplying energy to apartment buildings on a continuous basis. A demonstration engine-generator unit should be installed in a suitable apartment building to:

    a) Obtain the actual capital cost of such a unit;

    b) Determine its operating characteristics as a supplier of electricity or heat;

    c) Evaluate its economics;

    d) Assess its reliability and maintenance costs.

2. Since the ratio of electricity and fuel price is an important component in determining the economics of cogeneration, a study should be undertaken to identify the communities where installation of cogeneration units in apartment buildings would result in dollar savings, and hence reduce occupancy costs.

APPENDIX A

Table A-1 - Alternative I - Energy Produced & Cost Data
100 kW Engine

Table A-2 - Alternative II - Energy Produced & Cost Data
150 kW Engine

TABLE A-1

ALTERNATIVE 1

ENERGY PRODUCED & COST DATA - 100 kW ENGINE

	Operating Hours	Power Production kW	Power Production kWh	Heat Production kW	Heat Production kWh	Total Production kW	Total Production kWh	Value of Energy $ Demand	Value of Energy $ Energy	Cost of Fuel $
February (1980)	640	100	64,000	186	119,040	290	183,040	936.70	5,060.72	3,901.
March "	714	100	71,400	184	131,376	284	202,776	917.32	5,395.16	4,352.
April "	690	100	69,000	186	128,340	286	197,340	923.78	5,287.13	4,206.
May "	714	100	71,400	178	127,093	278	198,492	897.94	5,339.03	4,352.
June "	690	100	69,000	168	115,920	268	184,920	865.64	5,128.42	4,206.
July "	390	94	36,660	146	56,940	240	93,600	nil	3,568.32	2,260.
August "	714	85	60,690	132	94,248	217	154,938	700.91	4,768.39	3,549.
September "	690	85	58,650	132	91,080	217	149,730	700.91	4,673.61	3,430.
October "	714	96	68,544	150	107,100	246	175,644	794.58	5,039.68	4,212.
November "	690	100	69,000	164	113,160	264	182,160	852.72	5,092.75	4,206.
December "	714	100	71,400	171	122,094	271	193,494	875.33	5,273.55	4,352.
January (1981)	714	100	71,400	180	128,520	280	199,920	904.40	5,357.74	4,352.
TOTAL	8,074	1,160	781,144	1,977	1,337,470	3,141	2,116,054	9,370.23	59,984.50	47,378

TABLE A-2

ALTERNATIVE II

ENERGY PRODUCED & COST DATA - 150 kW ENGINE

	Operating Hours	Power Production kW	Power Production kWh	Heat Production kW	Heat Production kWh	Total Production kW	Total Production kWh	Value of Energy $ Demand	Value of Energy $ Energy	Cost of Fuel $
February (1980)	640	150	96,000	246	157,440	396	253,440	1,279.08	7,044.0	5,612.
March "	714	150	107,100	246	175,644	396	282,744	1,279.08	7,577.38	6,260.
April "	690	150	103,500	246	169,740	396	273,240	1,279.08	7,404.41	6,050.
May "	714	127	90,678	177	126,378	304	217,056	981.92	6,381.86	5,045.
June "	690	120	82,800	168	115,920	288	198,720	930.24	6,048.14	4,982.
July "	390	94	36,660	146	56,940	240	93,600	nil	4,134.96	2,348.
August "	714	85	60,690	132	94,248	217	154,938	700.91	5,326.57	3,924.
September "	690	85	58,650	132	91,080	217	149,730	700.91	5,253.47	3,792.
October "	714	150	107,100	246	175,644	396	282,744	1,279.08	7,577.38	6,260.
November "	690	150	103,500	246	169,740	396	273,240	1,279.08	7,404.41	6,050.
December "	714	150	107,100	246	175,644	396	282,744	1,279.08	7,577.38	6,260.
January (1981)	714	150	107,100	246	175,644	396	282,744	1,279.08	7,577.38	6,260.
TOTAL	8,074	1,561	1,060,878	2,477	1,684,062	4,038	2,744,940	12,267.54	79,307.34	62,843

APPENDIX B

Capital Cost

APPENDIX B

CAPITAL COST

1. For this study a preliminary equipment specification was prepared and mailed to four manufacturers or their agents:

   Crothers Power Division
   Cumming Ontario Ltd.
   Atlas Polar Co. Ltd.
   Total Power Ltd.

   The most appropriate units available on the market were quoted on as follows:

   a) Total Power Ltd. - 100 kW Engine-generator Model 90.0 KR
      - $38,000.

   b) Crothers Power Division - 150 kW Engine-generator Model G 342
      $67,000.

   These engines would be delivered complete with all controls, heat recovery equipment and the usual auxiliary equipment.

2. The enclosure required to house these units would be constructed in the basement out of concrete blocks. Since the heat exchanger or the exhaust gas circuits act as very effective silencers, the engine noise would be well within ambient noise level. The total floor space required is 35 m^2 at the cost of $17,500. for both alternatives.

3. The pipe connecting the unit to the storage tanks and the city water supply is calculated to be 125 mm in diameter for both alternatives. It is estimated that the distance between the proposed generator set location and the tanks is 38 m . The cost of installing the necessary piping in the basement is $7,600.

4. A cable suitable to carry the power output from the set would cost between $3,000. and $4,200., depending on the current.

5. Changes to the existing hot water delivery system would be minimal. The hot water from the engine would be connected in series with the existing electric water boilers. Failure of the engine to deliver the required amount of hot water would be supplemented with electric heaters. The cost of this connection and necessary valves is estimated to be $4,000.

6. Alternative II produces more energy than can be absorbed by the DHW system. A maximum of about 46 kW will be available for space heating. This energy can be used to heat the swimming pool and provide heat for the recreation facilities which are located within 30 m of the proposed engine set. The estimated heaters and piping for these 56 kW is $18,500.

In summary, the capital cost of the two cogeneration alternatives for 325 Bleecker St. is as follows:

Equipment	Alternative I	Alternative II
1. Engine-generator	$ 38,000.	$ 67,000.
2. Enclosure	17,500.	17,500.
3. Piping, valves, etc.	7,600.	7,600.
4. Cables & electrical connection	3,000.	4,200.
5. DHW connection	4,000.	4,000.
6. Space heating retrofit	nil	18,500.
7. Installation & commissioning	8,000.	11,000.
	$ 78,100.	$129,800.
8. Engineering & Management (15%)	11,715.	19,470.
9. Contingency (20%)	15,620.	25,960.
TOTAL	$105,435.	$175,230.

APPENDIX C

Calculation of Pay-back Period

APPENDIX C

CALCULATION OF PAY-BACK PERIOD

Alternative I - 100 kW Engine-Generator Set

1. Value of generated energy using Toronto Hydro rate is:

Demand	$ 9,370.23	Table A-1
Energy	$ 59,984.50	
Total	$ 69,354.73	

2. Operating Cost:

Fuel	$ 47,378.00
Maintenace	5,400.00
Total	$ 52,778.00

3. Saving with Cogeneration:

$69,354.73 - $52,778.00 = $16,579.73

4. Simple Pay-back Period:

$\frac{\$105,400.00}{\$\ 16,579.73} = 6.3$ years

Alternative II - 150 kW Engine-generator Set

1. Value of generated energy using Toronto Hydro rate is:

Demand	$ 12,267.54	Table A-2
Energy	$ 79,307.34	
Total	$ 91,574.88	

2. Operating Cost:

Fuel	$ 62,843.
Maintenance	$ 5,400.
Total	$ 68,243.

3. Saving with Cogeneration:

$91,574.88 - $68,243.00 = $23,331.88

4. Simple Pay-back Period:

$\frac{\$175,230.00}{\$\ 23,331.88} = 7.5$ years

APPENDIX D

Cogeneration Equipment

Preliminary Specifications

COGENERATION PROJECT

CMHC - OTTAWA

FIRM POWER SYSTEM

1.0 INTRODUCTION

1.1 The cogeneration system will supply electricity and hot water to an apartment complex.

1.2 This system shall operate continuously in parallel with an electric utility and be capable of operation as an isolated system.

1.3 The plant and its components shall be the product of firms regularly engaged in the manufacture of these products, and the generator plant shall be of a type that has been in commercial production for at least three years.

1.4 The fuel for the system shall be natural gas from a gas utility system.

1.5 The heat from the exhaust and the jacket cooling fluids shall be recovered to be used by the apartment building for domestic hot water and space heating.

2.0 SCOPE OF WORK

2.1 Design, manufacture, and supply a cogeneration power system, and test it for proper operation. The diesel generator set and heat recovery system shall be supplied complete with all the necessary auxiliary devices and equipment required for a proper function.

2.2 Fuel for the engine will be available from a gas utility. Provide loose exhaust silencer, and a suitable length of flexible hose complete with flanges for connecting to the exhaust pipe by others.

2.3 The heat recovery system shall be shipped separately and assembled at the site. Heat from the exhaust gases and the jacket cooling liquids shall be collected in a common header.

3.0 PERFORMANCE

3.1 Gas driven generator set shall be rated at 100 kW, 150 kVa, at 0.8 power factor for a continuous base load operation. The system will be operated as 600 volt, 3 phase, 4 wire output.

3.2 The system shall be designed with sufficient capacity and load response to permit for starting loads when the generator is carrying initial loads with a minimum of voltage dip.

3.3 The diesel generator set shall be capable of parallel operation with a utility.

3.4 The hot water temperature from the heat recovery system shall be 90°C - 95°C.

3.5 The minimum overall cycle efficiency (electricity and heat) at a rated power output at 0°C shall be 76%.

4.0 MAJOR COMPONENTS

4.1 The cogeneration system shall generally consist of the following components:

1. Prime Mover and Accessories
2. Alternator
3. Base
4. Control
5. Exhaust system
6. Air ducting (by others)
7. Heat Recovery system
8. Metering of hot water and electricity production
9. Relaying protection

APPENDIX E

Sample Calculation of Value of Produced Cogeneration Energy

Sample Calculation of Value of Produced Cogeneration Energy

1. For Toronto Hydro rates see attached.

2. Production for Alternative II: January - demand 396 kW
   - energy 282,744 kWh

3. Value of produced energy:

   - Demand: 396 kW x $3.23/kW/mo = $1,279.08

   - Energy:

First	39,600.	= 39,600 x $0.068	= $2,692.80
Next	39,600.	= 39,600 x 0.0298	= $1,180.08
Rest	203,544.	=203,544 x 0.0182	= $3,704.50
Total	282,744.		$ 7,577.38

APPENDIX F

Table F-1 - Monthly Commercial Electricity Costs for Selected Canadian Cities

Table F-2 - Provisional Rates for Purchase of Firm Capacity by Ontario Hydro for Cogenerators

Table F-3 - Calculation of Monthly Commercial Electricity Costs for Toronto (Ontario Hydro)

TABLE F-1

MONTHLY COMMERCIAL ELECTRICITY COSTS FOR SELECTED CANADIAN CITIES

CITY	EFFECTIVE DATE	(a) (b)	100 kW or 111 kVA[1] 25 000 kWh	1 000 kW or 1 111 kVA[1] 500 000 kWh	Run Out Cents/kWh/Over
Vancouver	April 1982		1 191.41	16 561.27	2.197/30 000
Calgary	October 1981		1 217.10	14 748.88	1.65/105 000 kWh & 200 kWh per kVA
St. Albert	October 1981		1 425.51	17 809.27	1.25/350 kWh per kW
Edmonton	April 1981		1 079.10	17 453.30	2.0/306 200 & 150 kWh per kVA
Grand Prairie	February 1982		2 361.07	37 512.05	5.62/400 kWh per kW
Regina	February 1982		1 370.41	19 082.33	1.86/all
Saskatoon	February 1982		1 337.96	18 578.39	2.1 & 2.05/all
Winnipeg	February 1979[2]		896.84	11 973.84	2.12/11 700
London	January 1982		918.25	15 903.25	1.45/2 180 000
Ottawa	February 1982		949.90	16 247.40	1.45/1 956 000
Sudbury	February 1982		1 110.48	18 352.98	2.91/10 000
Toronto	January 1982		1 252.80	16 623.00	1.82/200 kWh per kW
Montreal	January 1982		1 280.75	17 401.41	1.82/120 kWh per kW & 87 000 kWh
St. John's	December 1981		1 490.29	20 020.24	2.5/40 000
Fredericton	May 1981		1 719.40	27 959.40	4.34/5 000
St. John N.B.	May 1981		1 518.75	24 705.00	4.23/100 kWh per kW
Halifax	June 1979[2]		1 607.75	23 820.00	3.165/100 kWh per kW
Charlottetown	May 1982 (only)		2 967.17	49 672.92	7.997/200 kWh per kVA
Whitehorse	August 1981		2 190.00	39 730.00	6.47/400 kWh per kVA
Yellowknife	May 1982		3 676.59	72 283.65	13.95/50 kWh per kVA

(a) Billing demand
(b) Consumption per month

Date Issued: May 15, 1982
Page: 101
Superceded Date: November, 1981

1 90% Power Factor Assumed.
2 Rates have been frozen and are still in effect

154A-0104M-4

Table F-2

Provisional Rates for Purchase of Firm Capacity by Ontario Hydro From Cogenerators

Winter	$4.28 per effective kW* per month
Summer	$2.35 per effective kW* per month

* Effective kW to be determined as average kW guaranteed for delivery during the peak period of each month.

Energy Rates

Winter Peak	18.0 mills per kWh
Winter Off-Peak	16.1 mills per kWh
Summer Peak	15.5 mills per kWh
Summer Off-Peak	12.7 mills per kWh

Administration Charges to Parallel Generators*

If 4 channel digital metering required	$138/month
If upgrading from 2 to 4 channel digital metering required	$ 49/month

* Parallel generators connected to the system for the sole purpose of selling electricity may be required to pay additional metering costs.

Times of Use

Winter	- September through March
Summer	- April through August
Peak	- 7 a.m. to 11 p.m., workdays
Off-Peak	- 11 p.m. to 7 a.m., workdays plus all weekends and statutory holidays

Effective date: January 1, 1982

Table F-3

DATE ISSUED: MAY 15, 1982
PAGE: 627
SUPERSEDED DATE: NOVEMBER 15, 1981

CALCULATION OF MONTHLY COMMERCIAL ELECTRICITY COSTS FOR TORONTO

EFFECTIVE: JANUARY 1, 1982

BILLING DEMAND*:	(KW)	100	1 000
	(KVA)	111	1 111
CONSUMPTION/MONTH:	(KWH)	25 000	500 000
		($)	
DEMAND CHARGE:			
ALL AT $3.23 PER KW		323.00	3 230.00
ENERGY CHARGE:			
FIRST 100 KWH PER KW AT 6.8 CENTS PER KWH		680.00	6 800.00
NEXT 100 KWH PER KW AT 2.98 CENTS PER KWH		298.00	2 980.00
REST AT 1.82 CENTS PER KWH		91.00	5 460.00
SUB-TOTAL		1 392.00	18 470.00
LESS 10.% PROMPT PAYMENT DISCOUNT		139.20	1 847.00
TOTAL		1 252.80	16 623.00

* 90% POWER FACTOR ASSUMED

NOTE: CUSTOMERS SUPPLIED AT 1 000 KW AND MORE ARE SUBJECT TO A VOLTAGE DISCOUNT WHEN SUPPLIED AT 13 800 VOLTS.

SOURCE: TORONTO HYDRO
COMMERCIAL - INDUSTRIAL RATE

POOR

QUALITY

ORIGINAL